Impact

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From the Editor

There can be little doubt that Covid-19 has affected all our lives to a greater or lesser extent, with many of our work practices changing to accommodate the restrictions that have come and gone over the last two years. This has of course affected the Institute, however, like so many, it has adapted to address the challenges posed, with the Crash Day of 2021 moving to an online format., and the introduction of a series of webinars which to date have been very well subscribed.

Whilst Crash Day is set to return to the new venue of Darley Moor in June 2022, the webinars are also to continue, with a further five planned in 2022. The next webinar is on 27th April 2022 and is presented by Dr Chaz Dixon who will be discussing modern GNSS systems. The proceeding four webinars will be covering topics such as the Bosch CDR data, e-scooters, and a further input form Dr Gemma Briggs of the Open University on Human Factors.

Whilst Impact has continued throughout the pandemic, various difficulties have highlighted the need to adapt the managing of the publication to afford greater resilience in unexpected and challenging times to ensure the delivery of the journal remains uninterrupted. Consequently, I am very please to announce that a small editorial team has been formed to assist in sourcing material suitable for the journal and ultimately for the readership. The members of this team are, Mr Stephen Jowitt, Mr Norman Williamson, Dr Tom Connor, and Dr Stephen Ashton. I would first like to thank them all for their kind offers of assistance and look forward to working together in the continued delivery of *Impact*.

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General information concerning Membership Grades,

The Institute of Traffic Accident Investigators provides a means of communication, education, representation and regulation in the field of traffic accident investigation. Its main aim is to provide a forum for spreading knowledge and enhancing experience amongst those engaged in the discipline.

Further, the Institute seeks to promote a professional approach to traffic accident investigation and, through its rules and discipline procedures, to encourage honesty and integrity.

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Letters to the Editor are welcomed. Opinions expressed in letters and articles within *'Impact'* do not necessarily reflect those of the Editorial Board or the Institute.

Conspicuity Markings on the Back of Emergency Vehicles: Are they the Right Way Up?

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Abstract

Emergency service vehicles may be called upon to stop where other drivers would not expect to encounter a stationary vehicle, and thus should be as conspicuous as possible. The most common pattern that is used to enhance the conspicuity of emergency (and other) vehicles is the, 'inverted-V' pattern on the rear of such vehicles. Given that this chevron pattern contains linear perspective cues it has elements in common with a road receding into the distance and this may compromise its effectiveness in unambiguously signalling a stationary barrier. The purpose of this research was to determine whether the 'inverted-V' conspicuity chevrons may induce a perceptual distortion consistent with the pattern being perceived as a receding surface. A between-participants experiment was conducted, using perceived vertical line separation as a measure of the presence of perceptual distortion in a chevron pattern derived from that used on a fire appliance. Over half of all participants in the experimental condition saw the distortion; almost none in the control condition did. A Chi-square tested indicated that the difference was statistically significant ($\chi 2(df=2, N=233) = 51.385$, $p < 0.0005$; Cramer's $V = 0.47$), suggesting that the inverted-V pattern conspicuity pattern in such wide use is capable of inducing a perceptual distortion in a significant proportion of viewers.

Introduction

What do all the vehicles in Figure 1 have in common? Apart from the fact that they are all UK Fire & Rescue Service (FRS) vehicles, they all have the same pattern on the back – the ubiquitous 'inverted-V' chevron pattern. Although other patterns have been used (*Moore, 2013*) the inverted-V pattern is almost certainly the most widely used pattern found not only on FRS vehicles, but on almost all emergency vehicles, as well as vehicles used by a large range of utility and highway maintenance vehicles. The pattern appears worldwide and has been specified in some standards (e.g. NFPA 1901, 2009).

The rationale for the pattern is to make the vehicles more conspicuous, although there appears to be no scientific justification for this pattern, or any research to suggest that it is the most effective. While such markings almost certainly improve the visibility of emergency vehicles, there is evidence that,

Figure 1. *Emergency service vehicles displaying the ubiquitous 'inverted-V' chevron conspicuity pattern.*

even when the chevrons are theoretically visible to drivers, they are not always sufficient to signal an obstacle that must be avoided. For example, *Langham et al.* (2002) examined the use of such markings on the back of police vehicles, and suggested that such conspicuity markings are not always sufficient to prevent other road-users driving into police vehicles and claiming that they 'did not see them' – the classic 'looked but failed to see' (LBFS) incident.

Such incidents suggest that, even if a driver is aware of another vehicle at some level, this does not guarantee that they will respond to it appropriately (*Koustanaï et al., 2008*). This is particularly the case if a vehicle is doing something that the driver is not expecting; in which case the driver may respond, not to what the vehicle is actually doing, but to what they *expect* it to be doing. For example, a driver on a motorway will detect and register many other vehicles, including emergency vehicles. Most of them will not require any significant action on the part of the driver as they are moving at a similar speed. In contrast a stationary, or very slow moving, vehicle on the motorway will present a serious hazard that may well require avoiding action. Perceptually, however, it may present a very similar image to a moving vehicle (especially if it is not in an unusual position or orientation with respect to the carriageway) (*Edwards, 2005, cited in Crundall et al., 2008*).

The cues to suggest that the vehicle is not moving may be relatively few (especially at distance). The cue that observers appear to use to judge closing speed is the rate of change in size (looming), and this rate of change is very low at a long distances and very high at a short ones (*Lee, 1976*). The subjective effect is that looming will not be pronounced at long distances but becomes, 'optically explosive' at very short distances (*Schiff & Detwiler, 1979*).

A driver approaching a vehicle from directly behind will therefore receive relatively poor cues to indicate that such a vehicle is stationary. Given that emergency vehicles are often called upon to stop in traffic, it is essential that conspicuity markings, such as the inverted-V chevrons, support accurate perception of the vehicle on which the pattern is used and, unambiguously, indicate an obstacle to be avoided. The pattern should not only aid in detection of the vehicle, but should also help to cue the correct action on the part of the observing driver.

An additional *ad hoc* rationale (in addition to conspicuity) that has been given for the use of the chevron pattern is that it gives 'the impression of a barrier' (*Shulman et al., 2003*) to indicate, perceptually, an object to be avoided. The wisdom of giving the clear impression of a barrier is obvious. Given that the errors discussed above tend to occur without the driver's conscious awareness (people will not usually, deliberately and consciously, drive into the back of an emergency vehicle), a pattern that is intuitively perceived as a barrier should be beneficial.

One approach that might inform the design of conspicuity patterns is that of 'positive guidance'.

> 'Positive guidance is based on the premise that a driver can be given sufficient information about a hazard where he [sic] needs it and in a form he can use to enable him to avoid an accident' (*Alexander and Lunenfeld, 1990: ,* p. 272).

In order to do this, one of the key criteria is that the information should be presented in a form that is:

> 'Clearly visible, legible, accurate, relevant and unambiguous' (*Krauss, 2015*: , p. 78).

While the inverted-V conspicuity pattern satisfies most of the criteria above, it is debatable as to whether the information provided by the inverted-V pattern is unambiguous. For example, the pattern appears not to be consistent (see Figure 2) with the way guidance is given by other, commonly-used, markings on the highway.

Figure 2. *Unambiguous positive guidance?*

Thus the inverted-V pattern could be considered to indicate a 'straight ahead' direction of travel, rather than a need to stop, turn, or take avoiding action. Further strengthening the possibility that the current conspicuity markings do not intuitively suggest a barrier, cursory inspection of the chevron pattern makes it apparent that such a pattern shares some of the linear perspective cues of a road receding into the distance.

The linear perspective information provided by converging lines appears to be used by the visual system as a monocular cue for depth and space perception (e.g. *Gibson, 1950*; *Blessing et al., 1967*; *Wu et al., 2007*). Converging lines on a vertical surface facing the viewer may be perceived as lying on a slanting surface receding into the distance (e.g. *Braunstein and Payne, 1969*; *Cutting and Millard, 1984*). *Wu et al.,* (2007) demonstrated that converging lines on a flat surface may lead to the overestimation of distances to objects on that surface.

If converging lines do give the appearance of a surface receding in depth then the top of the pattern (in this case) should appear to be further away than the bottom. If this is the case then, as a result of what has become known as inappropriate constancy scaling (based on the illusory perception of the top of the figure as further away) (*Gregory, 1963*), then two identical parallel vertical lines placed on the conspicuity pattern would appear (falsely) to be further apart at the top than that at the bottom. The rationale for this perceived increase in separation is that, 'mentally,' people scale up objects that are perceived as further away (constancy scaling) to allow for the fact that the image on the retina becomes smaller the further away from the viewer the object is. We do not generally see, for example, identical objects at increasing distances diminishing in size – our percept is of the same size objects at different distances. If two objects give the same size retinal image but one is *believed* to be further away, it will be perceived as larger.

The study described here used the effect of inappropriate constancy scaling to test the hypothesis that the inverted-V conspicuity pattern may be perceived as a slanted surface. Such an effect would be likely to reinforce the notion that the pattern may indicate a forward direction of travel into the distance – conflicting with any indication of the need to stop, or to take action to avoid a hazard.

Material and Methods

A between-participants experiment was conducted using, in the experimental condition, a chevron pattern derived from the red and yellow pattern on the back of a fire appliance (see Figure 3a). The stimuli were presented on a PC display. The precise size and brightness of the pattern on presentation was not controlled, as it was felt that the way that the chevron pattern is viewed in the 'real world' is also quite variable. If an effect is there, and robust enough to be of practical

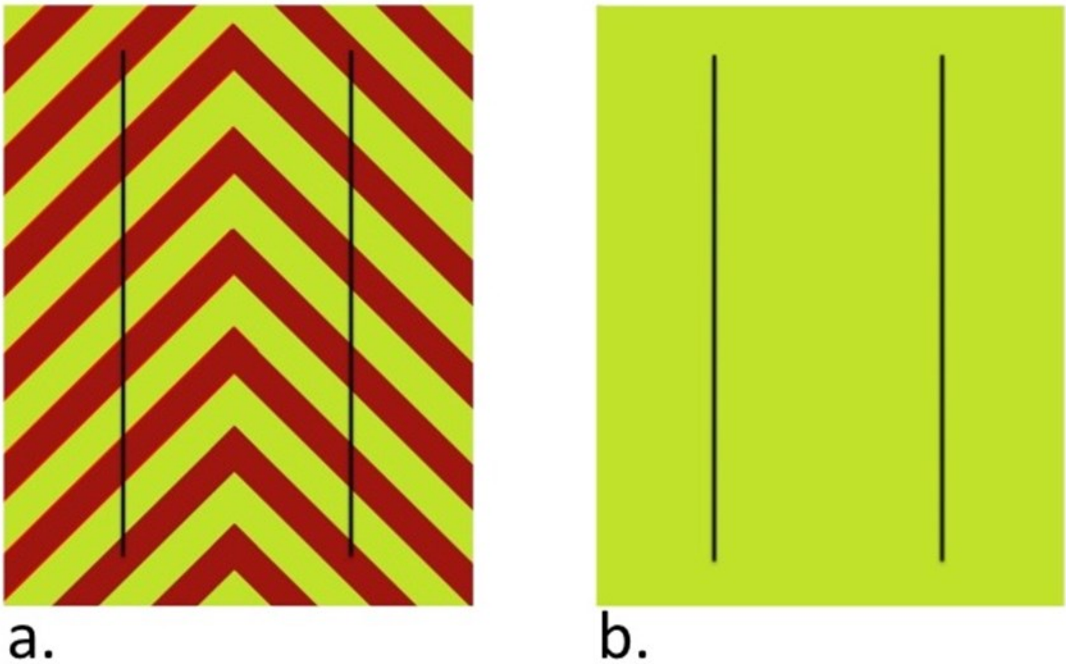

Figure 3. *An example of the stimulus configurations used in, a) the experimental condition, and, b) the control condition. In the experimental condition, the stripes were red and yellow and were derived from those on the rear of an emergency vehicle. The background of the control condition was either plain red or plain yellow.*

interest, then it should appear across minor variations in the stimulus. The vertical lines were varied across presentations so that they did not all, for example, end on a particular part (e.g. red or yellow stripe) of the pattern.

The stimuli in the control condition consisted of the vertical lines presented on a plain red or yellow background. The colour of the plain background was matched to either the red or yellow stripes in the experimental condition. (See Figure 3b.)

158 participants (66 male, 92 female, mean age 27.4 years, SD 12.7 years) were tested in the experimental condition and 75 (27 male, 48 female, mean age 26.3 years, SD 11.8 years) in the control condition. Informed consent was gained from each participant and they were also informed of their right to withdraw from the study at any time. Each participant was then shown a single stimulus pattern, either experimental or control. Viewing time was not restricted. Participants were asked to indicate verbally whether the vertical lines appeared to be further apart at the top, further apart at the bottom, or the same distance apart top and bottom. Each participant only took part in one condition, and so saw only one example of the stimulus, and gave a single response.

To control for any possible effect of participants showing a bias to choosing, for example, the first response option presented to them, the order of presentation of the options was counterbalanced across presentations. Thus in some presentations the 'wider apart at the top' option was presented first. In other conditions one of the alternative options was presented first.

Results

The number of participants in each condition (experimental and control) that reported each of the different possible line configurations (further apart at the top, further apart at the bottom, or the same distance apart top and bottom) was recorded. The frequencies are shown in Table 1. and graphically in Figure 4.

A 2 x 3 (Condition x Response) Chi-square test indicated that there was a significant

		Number of participants reporting the vertical lines as:		
		further apart at the top	further apart at the bottom	same distance apart top and bottom
Condition	Experimental	82	6	70
	Control	3	3	69

Table 1. *The number of participants in each condition that reported the different possible configurations of the vertical lines.*

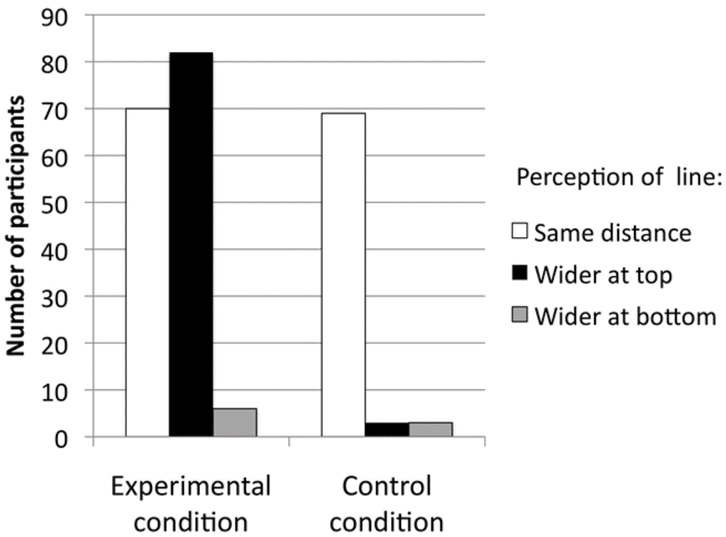

Figure 4. *A histogram displaying the number of participants that reported each possible configuration of the lines (wider apart at the top, wider apart at the bottom or same distance apart top and bottom) in the experimental and control conditions.*

difference ($\chi2(2, N=233) = 51.385$, $p < 0.0001$; Cramer's V = 0.47) in the distribution of the different perceptions of the vertical lines (i.e., whether the lines appeared: the same distance apart top and bottom/wider apart at the top/ wider apart at the bottom) between the experimental and control conditions. Over half of the participants perceived the lines as further apart in the experimental condition, almost none perceived them in this way in the control condition.

Discussion

If the chevron pattern generates a perceptual distortion suggesting a receding surface then one would expect the vertical lines to appear further apart at the top in the experimental condition but not in the control condition. More than half the participants in the experimental condition perceived the lines as further apart at the top, compared with almost none in the control condition (without the chevrons). The difference was highly statistically significant and the effect size was medium.

The pattern used in this study was displayed on a computer screen and was abstracted from the pattern used on the back of emergency vehicles. It did, however, appear to generate the illusion over minor variations of size, brightness, etc. It is possible that the effect may be less pronounced in the 'real world,' but it is also possible that it may be more pronounced. For example the perception of perspective cues is dependent on contrast (e.g. *Livingstone and Hubel, 1987*), and the patterns used in this study were of relatively low contrast. On emergency vehicles, the contrast could be far higher, especially at night, when it may be the case that only one of the colours in the chevron pattern is retro-reflective. Furthermore, the distortion of vertical line separation may be evident in the door hinges of the vehicles in Figures 1 and 2, suggesting that the illusion may be present with more realistic stimuli.

The data from this study suggest that the chevron pattern used so widely on emergency vehicles across the world may be capable of inducing an illusion that may be, at least in part, generated by misperceptions of depth. Although factors other than misperceptions of depth may also contribute to the distortion of the lines, the overriding consideration is that the chevron pattern does contain linear perspective cues and can act to distort visual perception in a significant proportion of those that view it.

Given that perhaps the most safety-critical function of the chevron pattern is to alert road users to a stationary emergency (or other) vehicle in their line of travel, the chevron pattern should satisfy two key criteria. The first criterion is that the pattern should be highly visible, and there is little doubt that this is the case. The second criterion is that the pattern should, intuitively and unequivocally, be perceived veridically - especially given the large proportion of accidents in which perceptual factors appear to be a contributory factor. A pattern that can induce an illusion (possibly based on illusory depth) that is indicative of a perceptual distortion does not satisfy the second criterion. A pattern containing linear perspective cues reminiscent of a receding surface is unlikely to provide the strongest possible cue to suggest a barrier that must be avoided.

In conclusion, it appears surprising that a pattern that is so widely used in such safety-critical situations is so under-researched. The data presented in this paper suggest that the inverted-V conspicuity pattern may be capable of giving rise to an illusion suggestive of distorted perception. It would certainly, therefore, be worth researching further the effectiveness of this pattern to establish whether it is the optimal pattern to use on emergency vehicles. Such research could begin by considering whether a pattern that has similar linear perspective cues to a road receding into the distance is the best one to paint on the back of a vehicle that may have to stop in traffic.

One simple solution may be to apply the pattern the other way up.

Acknowledgements

The authors are grateful to Dr. Paul Harrison and Dr. Martin Langham for their helpful advice on this study.

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WREX 2023 will be hosted by a large group of international associations. Representatives from 24 groups are hard at work planning for, and refining, the next event. WREX 2023 will feature many of the top international speakers in the ever-expanding field of collision reconstruction. Crash test day at WREX 2023 will utilize multiple crash test teams to provide numerous high speed crash tests with minimal down time. The new off-site crash test location will facilitate easy access between staged collision events and provide for a better attendee experience. The Interactive Field-Testing Day (a.k.a. "Reconstruction Midway") at WREX 2023 will be held at a larger venue on site at the host hotel to accommodate even more exhibitors. High quality sit-down lunches will be served each day of the conference and are included as a part of your event registration fee. For those intent on getting the most bang for their training buck, evening presentations, including poster presentations of select collision reconstruction topics, will be available at WREX 2023. We hope to be awarded 42 ACTAR CEUs, but do not yet have final approval.

Registration is available at wrex.org. Attendees who pre-registered need to visit the website again to fully register.

WREX 2023 has already attracted over 750 attendees who have registered and pre-registered. We have also signed on numerous vendors so that attendees can see the latest reconstruction gear. WREX 2023 is also gaining support from numerous sponsors in order to provide the best experience possible for our attendees. **Remember** the attendee room block at the host hotel sold out in 2016. The WREX 2023 planning staff encourages you to reserve your hotel room ASAP to ensure your ability to stay on site while attending this sure-to-be spectacular event. Room reservations may now be made on our website at wrex.org.

If you were unable attend WREX 2016, ask someone who did. We will see you at WREX 2023.

High-speed crash test evaluation with PC Crash

Hannes Winkler
Zurich Forensic Science Institute

In the case of high-speed accidents involving passenger cars, for example on motorways, there may be uncertainties in accident reconstruction regarding the exact reconstruction of the real accident using accident analysis software.

With the accident analysis software PC Crash a crash test should be reconstructed as realistically as possible and it was to be shown if or which parameters are difficult to determine.

Introduction

With the ongoing development of motor vehicles, their performance has also increased. Modern passenger cars perform, on average better in engine and braking parameters, have tighter chassis and more advanced driver assistance systems than older models. Modern vehicles convey a feeling of relative safety even at high speeds.

The behaviour of some drivers also appears to be "evolving" towards greater willingness to take risks, greater confidence in technology or a lower sense of danger or responsibility. "Speeding offences"[1] - offences with massively excessive speeds - seem to be increasing compared to the past [1,2].

The accident reconstruction uses established collision analysis software such as PC Crash[2], AnalyzerPro[3] or others. The apprehension imposed that the calculation models of the collision analysis software, which were approved many years ago, might reach their limits in collisions at high speeds or that the results might deviate too much from reality. Although the classical principles of physics apply to both low-speed and high-speed accidents, the question arose whether the impulse module used for high-speed accidents reconstruction have any relevant inaccuracies?

As far as we know, almost no current research has been done on this subject or was published in the literature.

This paper shall investigate the application of collision analysis with PC Crash by means of a well documented high-speed crash test.

Examination

Crash Test

The *"Institute of Traffic Accident Investigators (ITAI)"* in England has started to carry out crash tests at a former military airfield on their "Crash Test and Research Day" in June. Due to the almost unlimited space available, it is possible to carry out spectacular crash tests at high speeds.

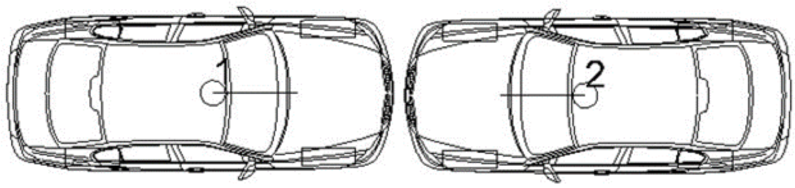
At the "Crash Test and Research Day" 2018, Test 7 involved a frontal collision with almost complete coverage of a Jaguar X Type with a collision speed of around 143 km/h (89 mph) against a stationary Vauxhall/Opel Astra.

To document the tests various test tools and measuring systems were used. Drones, cameras, high-speed cameras, accelerometers and other tools were used. The test tools and measuring systems were partly operated by the crew or by visitors. Following the "Crash Test and Research Day" 2018, the participants were provided with a collection of various pictures, videos and data sheets on the tests performed.

Crash Test Evaluation

The evaluation of test 7 was carried out in particular using videos with drones and high-speed videos. The post-collision movements of the Jaguar X Type and Opel Astra were derived from the videos. The video recordings

Test: 7 12:30	Crash Type: Car v. Car	
Test Configuration:	Head on impact 100% overlap	



Target Vehicle	Bullet Vehicle	Bullet Vehicle
ITAI Number: 12	ITAI Number: 30	Immediate Pre-impact Speed:
Make/Model: Silver Vauxhall Astra	Make/Model: Silver Jaguar X Type	89mph
Mass: 1,120kgkg	Mass: 1,400kg	

***Figure 1**. "Overview table of test vehicles from "List of Crashes and Vehicle Data."*

can be examined with the software "Avidemux 2.7". This software allows the step-by-step observation of single frames in videos.

In PC Crash, the post-collision paths of the two vehicles had been reproduced with overlaying images. The positions of the vehicles were inserted in every fifth single frame and the distances between the positions were measured [3, 4].

The video recording frequency (fps; frames per second) allows the allocation of the time duration between the single images. The changed positions of the vehicles and the elapsed time allows to reconstruct the spatio-temporal post-collision movement of the vehicles. For five successive images a time

***Figure 2**. Image overlay of the post-collision paths of the two vehicles*

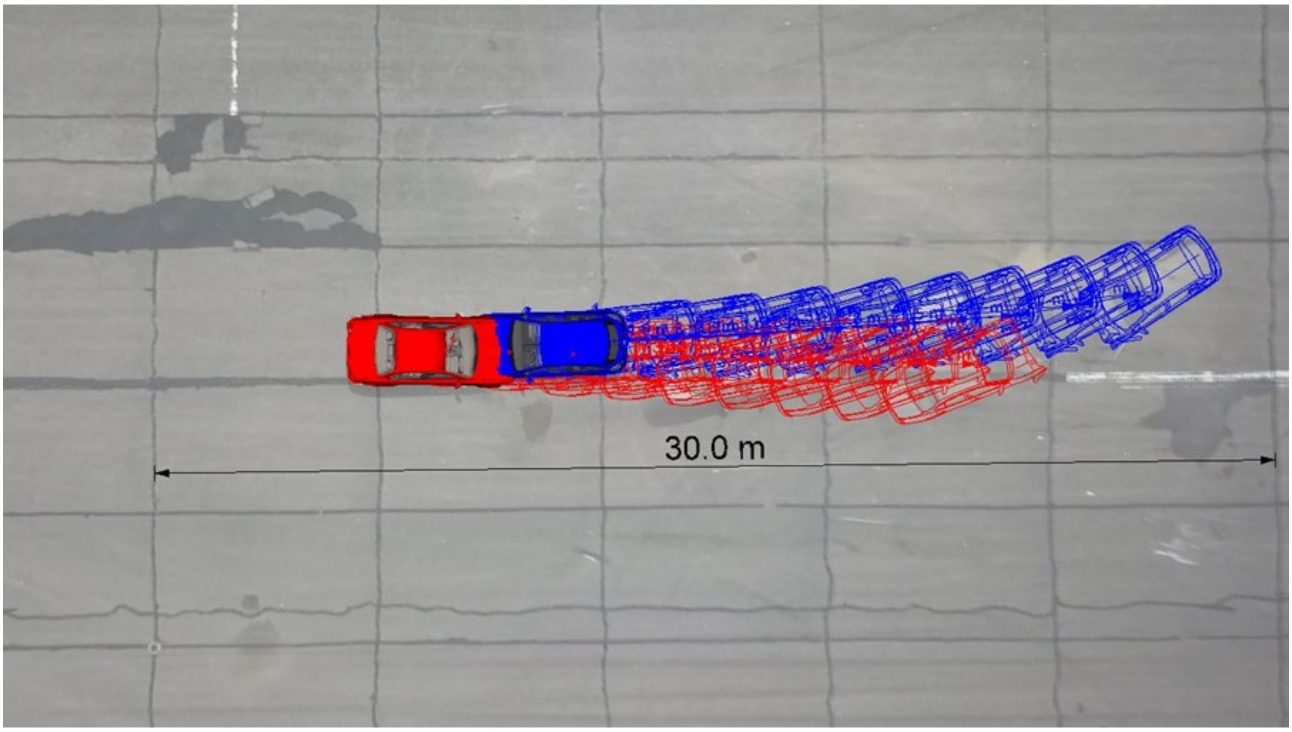


Figure 3. *Reproduction of the post-collision paths of the two vehicles from overlaying images*

duration of about 0.083 s elapses. The distances between the vehicle positions divided by the time of about 0.083 s result in average speed values of the vehicles for the respective sections. The speed values are shown in the following graph on the post-collision speeds of the two vehicles. The inserted linear trend lines allow to smoothen irregularities of the calculated speed-dots regarding the vehicle positions.

The linear post-collision speed of the Jaguar X

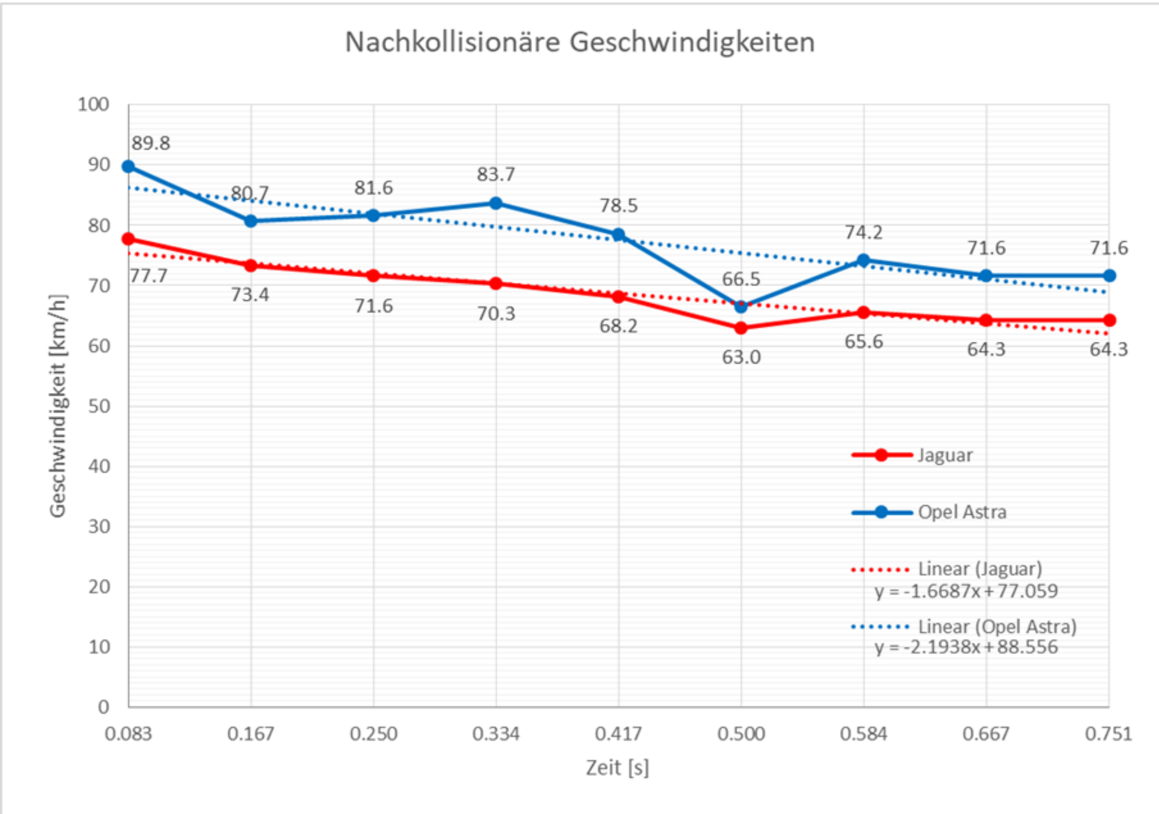


Figure 4. *Graph of the post-collision speeds of the two vehicles (from video analysis)*

-type was around 75 km/h at the beginning (0.083 s) and around 62 km/h at the end (0.751 s). The Opel Astra had a speed of around 86 km/h at the start (0.083 s) and around 69 km/h at the end (0.751 s).

In the side view of the collision, a clearly visible rear lifting of the two vehicles and a pushing down to the ground of the fronts are observed. This movement results from a torque around the lateral axis of the vehicle. This torque results from the centre of the vehicle gravity being above the idealised contact point between the two vehicle fronts. Typically, this rear lifting as well as pushing the fronts down to the ground produces impact marks in the asphalt on the scene of documented high-speed accidents.

PC Crash Collision Analysis

The collision analysis in PC Crash was carried out using the impulse module crash simulation according to *Kudlich-Slibar* [5]. In this module, the two vehicles are placed in the positions of maximum dynamic penetration, the pre-impact speeds are entered and the point of impact and the contact plane are defined. The maximum penetration depth was selected on the basis of the single images from the video recording. It was visually determined that the Opel Astra had already started moving one frame before the maximum penetration occurred. The following single frame with the maximum penetration was selected as starting point. The two vehicles were superposed with the positions of maximum penetration.

According to above post-collision speeds, for the separation of the two vehicles an impact-point-release-velocity of about 10 km/h was selected by adjusting the k-factor [6]. Then the impact calculation was carried out.

The post-collision speed of the Jaguar X Type was calculated one single frame after the maximum penetration at around 75 km/h and that of the Opel Astra at around 86 km/h.

The impulse calculation resulted in a post-collision speed of around 75 km/h for the Jaguar X Type and around 85 km/h for the Opel Astra. The post-collision speeds of the impulse calculation correspond appealingly well with the post-collision speeds resulted

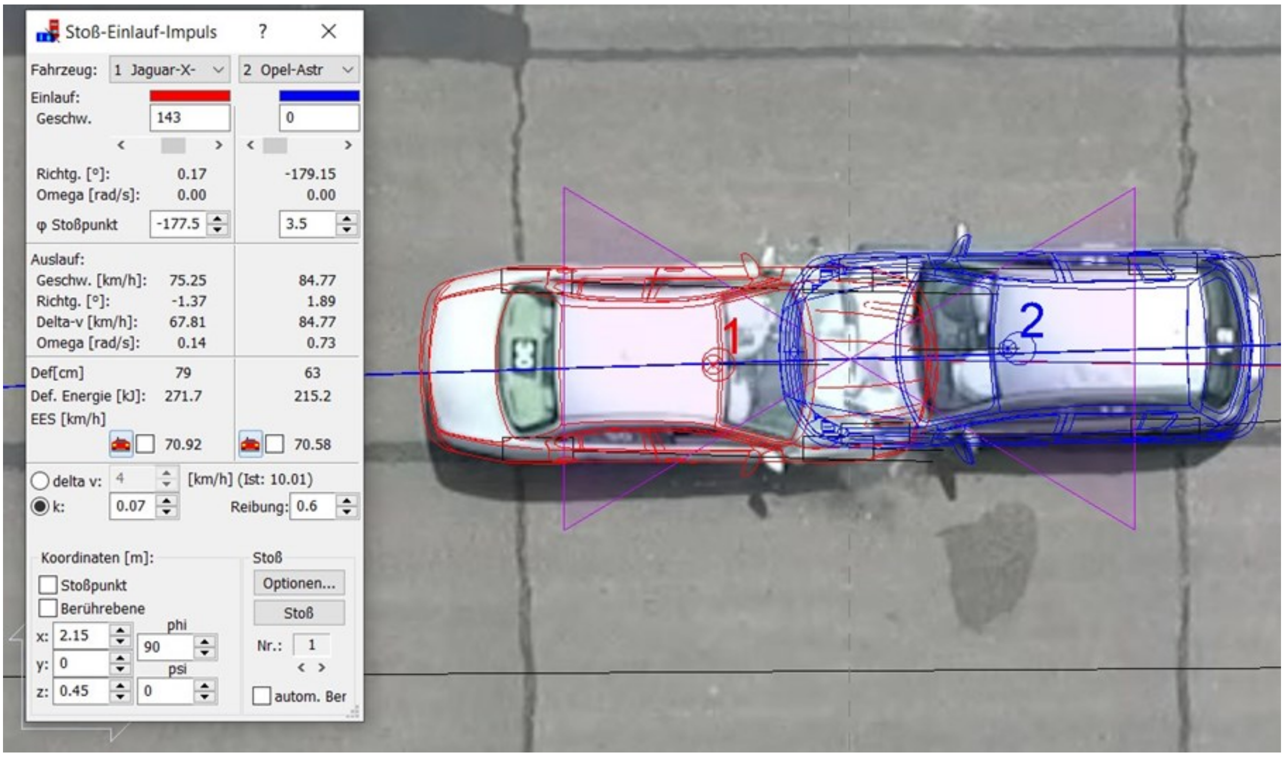


Figure 5. *Collision analysis with the impulse module crash simulation of PC Crash*

from the video evaluation. A further optimization of the impulse calculation was aimed at later.

Verification of post-collision movements

The verification of the spatio-temporal overlap of the post-collision movements of the Jaguar X Type and the Opel Astra from the video with the simulation in PC Crash showed, that the rear of the two vehicles lifted off less in the simulation than it is apparent in the video. A more intense lift-off of the rear could be achieved by adjusting the heights of the two vehicles centres of gravity. By increasing the centre of gravity while using the same height of contact point during impact, the torque around the lateral axis of the vehicle increases, which results in a more intense lift-off of the rear. The original height of the centre of gravity at 0.5 m was increased to 0.58 m for the Jaguar X Type and to 0.62 m for the Opel Astra. Alternatively, the height of the contact point could be reduced. The high-speed video shows during vehicle penetration the rears being raised and the fronts lowered. A further optimization for the heights of the contact point and centres of gravity was not intended.

The lifting of the rear wheels favours the turning ability of the two vehicles around the vertical axis after the collision. When the rear wheels of the Jaguar X Type hit the ground again, the rotation was abruptly reduced, which was visually equal to a "counter-steering" in the vehicle's movement.

For the post-collision movements, a constant deceleration of 6 m/s^2 was used for both vehicles, whereby a larger or maximum partial braking factor was assigned to the front wheels due to the deformation.

In addition, when checking the spatio-temporal overlap of the video with the simulation, it was found that the vehicles were less separated from each other in the simulation compared to the video. In the diagram of the post-collision speeds, it can be seen that in the first approx. 50 ms the post-collision speed of the Jaguar X Type increases and that of the Opel Astra decreases. This reduced the speed difference at the beginning of the separation considerably below the impact-point-release-velocity of primarily about 10 km/h.

In the simulation, the vehicles separate too little from each other in the post-collision movements compared to the real separating in the post-collision movements of the vehicles in the video.

The pre- and post-collision values are calculated at the impact point. After the collision are no more contact forces present between the vehicles until the next impact is detected. After the impact, the post-collision parameters and those of the sequences take effect on the ground via the wheel contact forces or, as the case may be, chassis contact forces. The reduction of the speed difference at the beginning of the post-collision movement could not be satisfactorily corrected at first. Finally, the insufficient separation during the post-collision movement was "corrected" by increasing the impact-point-release-velocity or by adjusting the k-factor in the impulse calculation from about 10 km/h to about 16 km/h.

During further examination of the simulation, we detect in the post-collision movement an acceleration peak within the first 30 ms relative to the centre of gravity of the Jaguar X -Type of up to approx. 20 m/s^2 and the Opel Astra of up to approx. 13 m/s^2 in the longitudinal direction of the vehicle as well as for the Jaguar X-Type of up to approx. 21 m/s^2 and the Opel Astra of up to approx. 14 m/s^2 in the vertical direction. These accelerations are due to the nodding of the vehicles and lead to a reduction of the speed difference between the vehicles at the beginning of their separation.

Overlap in the plan view

The simulation of the vehicles post-collision movements in PC Crash was brought into approximate overlap with the video recording of the drone camera. In the course of the

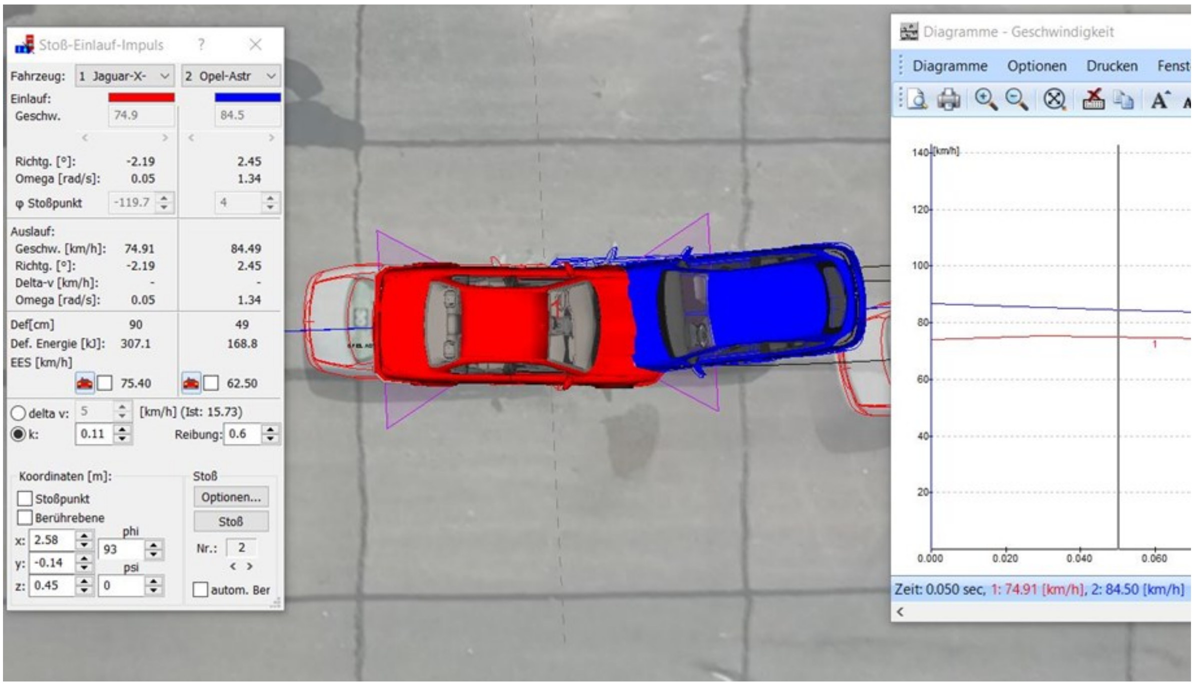


***Figure 6**. Approach of the post-collision speeds at the beginning of the separation movement (red mark)*

review and verification work, parameters like the impact point and the contact plain as well as the starting values were adjusted. From the position of maximum penetration to a further position (0.417 s) and a last position (0.735 s), the two vehicles showed in plan view an appealingly good coverage in the post-collision movements. The remaining shortage in the developed simulation is that the vehicles show in the last position slightly too positive speed directions (deviation approx. 6° respectively 11°). However, a further optimization of the impulse calculation was not aimed for now.

A comparison in the top view shows an appealingly well overlap between the video recording of the drone and the simulation with PC Crash.

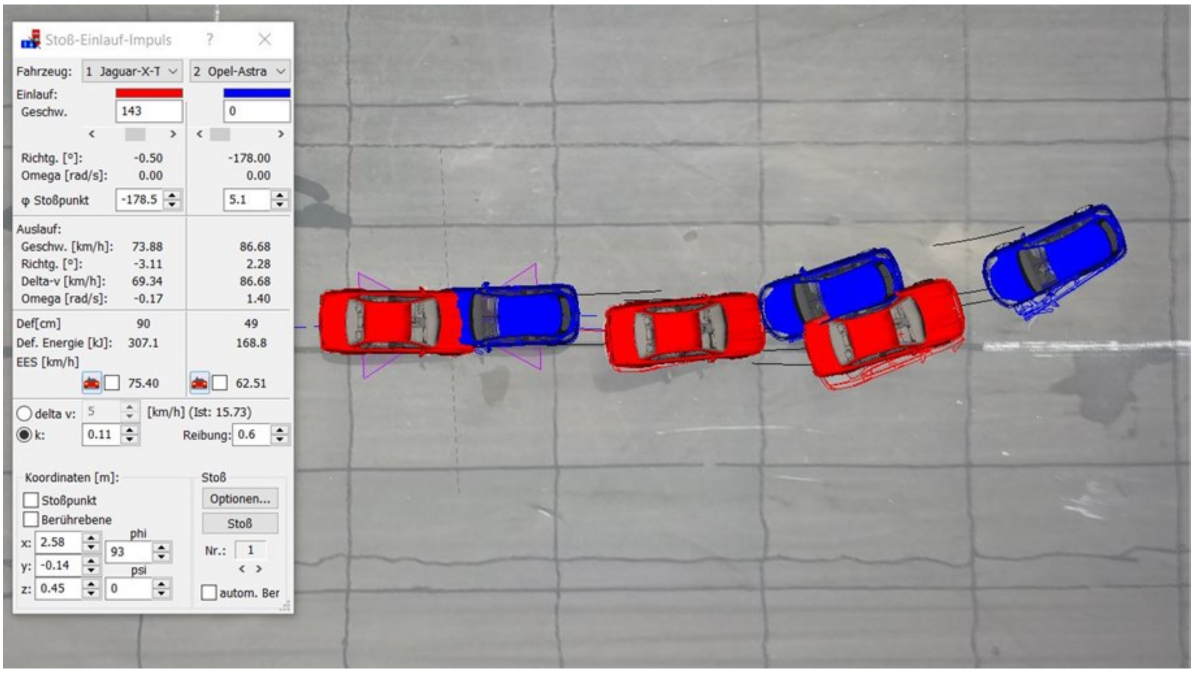


***Figure 7**. Appealingly well overlap between video recording and simulation*

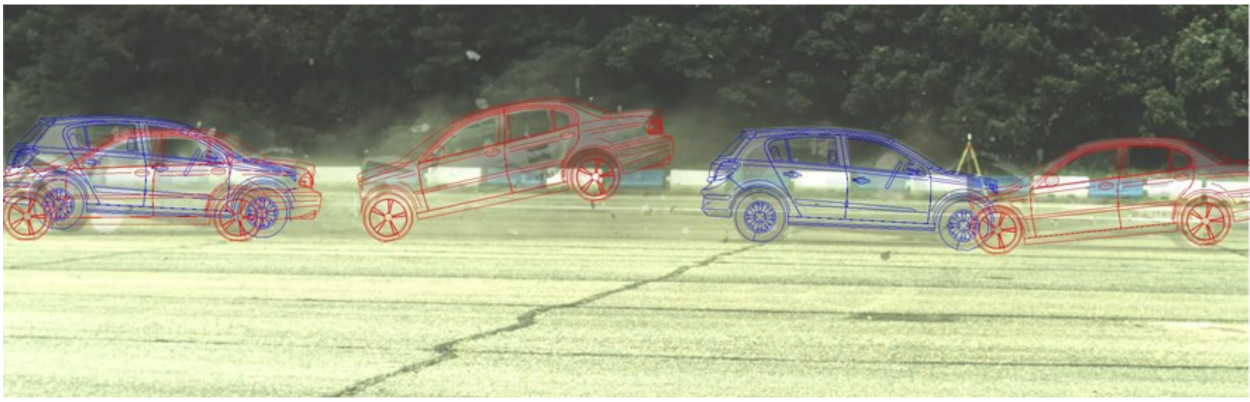


Figure 8. *Side view of the vehicles positions in the video*

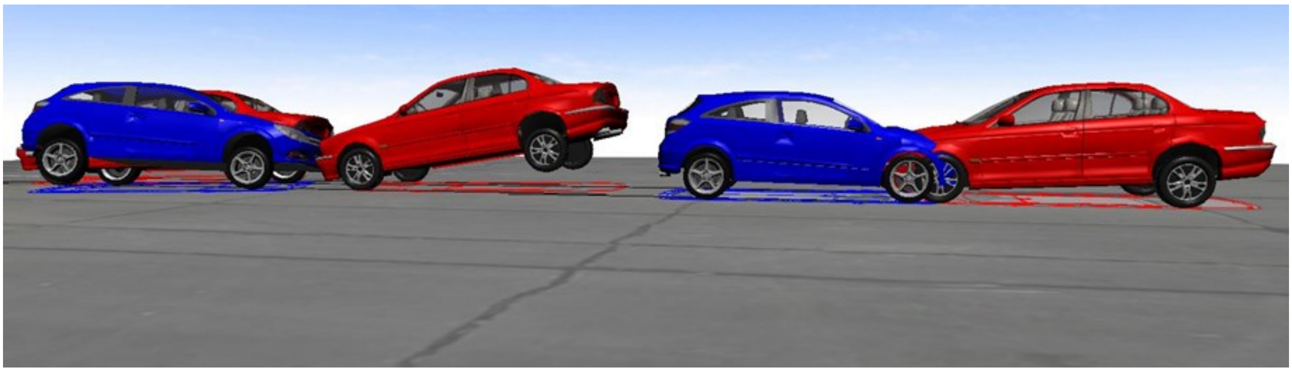


Figure 9. *Side view of the vehicles positions in the simulation*

<u>Overlap in side view</u>

The simulation of the vehicles post-collision movements was brought into approximate overlap with the recording of the high-speed camera. The two vehicles showed already a nod in the position of maximum penetration. A nod of 2° was chosen for the Jaguar X Type and of 1.5° for the Opel Astra. In a further position (0.417 s) the vehicle rears were raised. In a last position in the side view (0.697 s) the Jaguar X Type was at the edge of the picture and the Opel Astra already outside the picture.

A comparison in side view shows a good overlap between the high-speed video overlaying images and the simulation with PC Crash.

In the view in the direction of driving there is no video recording available. A rolling of the vehicles at maximum penetration cannot be determined from the videos. In the simulation, the roll values were set to zero at the starting values.

The mutual matching between the top view and the side view could be improved by further optimisation of the simulation – e.g. when the rear wheels hit the ground. No further improvement was sought.

Summary

In this study, the reconstruction of a real high-speed crash test – bullet vehicle at 143 km/h against target vehicle – was attempted with the impulse module of PC Crash with the aim to faithfully reproduce and achieve an overlap between the simulation and the real movements during the post-collision movements of the vehicles.

The impulse calculation finally resulted in a post-collision speed of about 74 km/h for the Jaguar X Type and about 87 km/h for the Opel Astra. Compared to the post-collision speed of the Jaguar X-type of about 75 km/h and the Opel Astra of about 86 km/h from the video, we think that this is a good coverage of the results.

The apprehension that the impulse calculation of the collision analysis software might reach their limits or that the results might deviate too much from reality in collisions with high-speed accidents was not confirmed by this study.

Although the collision is reduced to one point in time, an exact reconstruction for high-speed accidents can be produced using the impulse module of PC Crash in this example case. A precondition for this is that the collision parameters are carefully selected. The position of the centres of gravity of the vehicles, the impact-point-release-velocity, nodding and rolling at the impact point influence the vehicles' post-collision movements.

Tolerances in the reconstruction of high-speed accidents can occur especially before and after the impact calculation, i.e. in the penetration and separation movements during the collision.

In the penetration movement up to the point of maximum dynamic deformation, in particular changes in the positions of the centres of gravity of the vehicles, nodding and rolling have an influence. A common assumption for the height for the centres of gravity of the vehicles for passenger cars in reconstructions of 0.5 m may be too low. Adjusting the height of contact points or centres of gravity on the vehicles can give better results.

Of particular importance in the separation movement during the collision are the impact-point-release-velocity and its progress as well as the rotations around the vertical, lateral and longitudinal axes of vehicles, which are shown in nodding, rolling, the chassis hitting the ground and the wheels lifting off the ground.

In the post-collision movements after vehicle separation, the decelerations and the rotations around the vertical, lateral and longitudinal axes of the vehicles are important. A vehicle with lifted rear wheels achieves more rotation in the reconstruction than a vehicle with all wheels in contact with the road surface.

Acknowledgements

I would like to thank Dr. Andreas Moser, DSD – Dr. Steffan Datentechnik – for his professional support in this work

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[3] AnalyzerPro; AnalyzerPro KG; Salzburg (A)

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The journal reaches specialist police officers, researchers, private consultants, engineers and other professionals involved in collision investigation.

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Several countries tighten e-scooter rules as German study finds huge underreporting of injuries

Feb. 2022

Several governments are updating rules on e-scooter use, as more evidence emerges of the particular risks faced by users of this novel mode of transport.

Denmark introduced mandatory helmets from 1 January this year, following research that showed the risks of an e-scooter crash are seven times higher than for bicycles.

Norway will also introduce mandatory helmets for children up to 15 years old later in the spring and introduce a drink-drive limit of 0.2 g/l Blood Alcohol Concentration (BAC) – the same as for car drivers. Liability laws and the question of whether e-scooters should be allowed on pavements are also being looked at, ETSC understands. Norwegian research has shown the risks are up to ten times higher for e-scooters, compared to bicycles.

Spain is introducing minimum technical standards for e-scooters and will also require mandatory helmets from next month.

In Germany, new research from a hospital in Essen found that hospitalisations after e-scooter crashes were not reported to the police 74% of the time. Germany is one of the only countries to collect e-scooter crash data as a separate category – but relies exclusively on police data, suggesting official figures are severely underreported.

The study authors recommend helmets due to large numbers of head injuries, in particular when riders fall after the small wheels of their e-scooter come into contact with a curb.

Drink-riding also remains a problem, despite Germany having the same limits as car drivers. The authors call for more checks on e -scooter riders on weekends in city centres when most hospitalisations occur.

Meanwhile new data from German insurers found that third-party claims after crashes involving e-scooters are similar to crashes involving mopeds. Several countries now classify e-scooters as motor vehicles, but many still consider them to be equivalent to bicycles

Making Roads Safer for Older Drivers

November 2021

- Older drivers (70+) do not pose a significant risk to other road users, but their relative frailty means that they are over-represented in serious crashes – particularly those over 80
- For drivers over 80, the rate of being killed or seriously injured, per licence held, is as high as for those aged 21-29
- Serious injuries among the young reflect inexperience; for older drivers it's about their fragility
- We have an ageing population so expect huge increases in licences held by older drivers
- So older driver deaths will increase if we do not take decisive action now
- Car driver deaths in the 70-79 age group are forecast to increase by 40% over the next 20 years, and by more than a quarter in the 80+ age group

A series of recommendations will help curb these increases.

Setting targets to reduce deaths and serious injuries for drivers over 70 by 50% by 2030 and to have a longer-term aspiration for zero deaths by 2050 is a key recommendation in *Supporting Safe Driving into Old Age*, a summary report issued today by a team of experts funded by the Department of Transport.

Other proposals include:

- introducing mandatory eyesight testing with an optometrist or medical practitioner providing a driver 'MOT' of eyesight at licence renewal at the age of 70 and at further renewals;
- a programme of making T junctions safer – a notorious risk-point for older drivers;
- immediate research into the impact of physical and cognitive medical conditions, including diabetic peripheral neuropathy, that may contribute to pedal confusion;
- standardised content for Driving Appraisals and certified and trained instructors to assist older drivers;
- and a national roll-out of an alternative to prosecution for careless driving for older motorists.

For vehicles, the report also recommends that the government takes on board:

- EU standards of vehicle safety technology and
- further research into advanced occupant restraint systems such as split buckle or crisscross seat belts in recognition of the frailty of older drivers and passengers.

The Older Drivers Task Force was originally commissioned in 2016 to make its recommendations, acknowledging the importance of people living an active and healthy life into older age, and that age itself does not give an indicator of how fit a person is to drive. The aim is to support older drivers to continue to drive while they are still safe to do so.

Today's report is published by the Road Safety Foundation which led the Task Force. Executive Director Dr Suzy Charman says: "There have been some developments since the previous review, but we want to increase the pace of progress to ensure that we do not see the expected rise in the number of older drivers killed or seriously injured in road crashes. Key recommendations such as introducing mandatory eye tests at licence renewal at aged 70 are considered essential and lifesaving.

"We hope the Department for Transport welcomes the report and can provide the leadership necessary to ensure these recommendations are taken forward. Not only will this make driving safer for older drivers, but it will also provide a legacy of safer roads for generations to come."

John Plowman, chair of the Task Force, says in the report foreword: "I am grateful for the contributions of all members in following up the review and to the Road Safety Foundation for their support throughout our work. We are ready to help in whatever way we can to support the action now needed to make driving safer for older drivers, a vulnerable and growing sector of our community."

Supporting Safe Driving into Old Age reports are available here:
https://roadsafetyfoundation.org/project/safe-driving-into-old-age/

Media contact: Becky Hadley 07733 054839 becky.hadley@hadstrong.com

About the Older Drivers Task Force

The following organisations and individuals made contributions to the work of the Task Force and its members are in broad agreement with its findings • Autoliv • Rob Heard • Kit Mitchell • Department for Transport (Observer and Funder) • DVLA (Observer) • Hadstrong PR • Bert Morris • Parliamentary Advisory Committee on Transport Safety (PACTS) • RoadSafe • Professor Steve Taylor • Elizabeth Box, RAC Foundation • Brian Morgan - CAMC • Dr. Carol Hawley – Warwick University • Keya Nicholas • Lisabeth Miles • Neil Greig, IAM RoadSmart • Nick Lomas • Peter Grayner • Rob Needham – RoSPA • Professor Dilwyn Marple-Horvat - Manchester Metropolitan University.

About the Road Safety Foundation

The Road Safety Foundation is a UK charity, founded in 1986, that aims to help reduce road trauma through employing the Safe System philosophy by:

- Identifying investment packages likely to give high returns and analysing the safety performance of roads over time.
- Providing the approach, tools and training necessary to support road authorities in taking a proactive approach to road risk reduction.
- Undertaking research to progress knowledge and policy.

Over the last 20 years, the charity has maintained a particular focus on safer road infrastructure through the establishment of the European Road Assessment Programme and the development of the International Road Assessment Programme (iRAP) and its protocols for measuring infrastructure safety. The RSF is responsible for supporting the Road Assessment Programme in the United Kingdom, and its work serves as a model of what can be achieved, with key research and innovation being replicated in RAP programmes across the world. Recently, the charity has:

- Supported DfT's Safer Roads Fund carrying out surveys of the 50 highest risk local 'A' roads in England, training local authorities, and modelling the impact of schemes that together made the £100 million investment portfolio
- Provided support and technical insight to Highways England in their SRN-wide iRAP initiative
- Undertaken an independent review for the Office of Rail and Road into how Highways England prioritises investments to improve safety outcomes on the strategic road network
- Led the Older Drivers Task Force report with government support to develop the national Older Driver Strategy Supporting Safe Driving into Old Age

For more information and our full library visit roadsafetyfoundation.org

Find Road Safety Foundation on social media: The Road Safety Foundation is a UK charity advocating road casualty reduction through simultaneous action on all three components of the safe road system: roads, vehicles and behaviour.

For more information visit www.roadsafetyfoundation.org @SafeRoadDesign

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Impact

Submissions invited

Next Edition July/August. 2022

As ever, the Editor would be very pleased to hear from members, non-members or subscribers, who have produced material that they feel would be of interest to readers of *'Impact'*. Details of research projects or relevant collision investigation testing would be particularly welcome. Attracting sufficient numbers of articles for publication in the Institute's journal remains a difficulty! Whilst the Editor is delighted to receive papers from overseas contributors, a greater supply of 'home grown' material would also be very welcome.

If you have any questions regarding the publication of an article / paper, or simply wish to discuss the possibility of preparing a piece for the journal, please contact the Editor at **editor@itai.org**

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ITAI Members - £910.00 - Non-Members - £985.00

Charges cover training for the five days; a copy of the latest version of Dr Muttart's reference book 'Drivers' Responses in Emergency Situations' and use of the I.DRR programme for 3 months.

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How realistic is the Biofidelic Dummy in terms of Reconstruction Parameters and Biomechanics

Andreas Schäuble[a], Michael Weyde[b]

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Abstract

In order to improve the preciseness in pedestrian-vehicle accident reconstructions, a new biofidelic dummy had been developed. The objective of this work was to biomechanically validate the biofidelity of this new kind of anthropomorphic testing device (ATD). Therefore, nine crash tests have been conducted with the Biofidelic Dummy and the results were compared with four crash tests ear-lier performed with the Žilina Dummy, an ATD widely used in accident research due to its low cost and robustness, post-mortem human subject tests obtained from published research papers and 21 real-world pedestrian accidents.

The topics analysed were dummy trajectories, vehicle damages, the C-ratio, throw distances and dummy "injuries".

The Biofidelic Dummy performs more human-like than the Žilina Dummy in regards to the trajectories and causes vehicle damages which are comparable to those caused by a pedestrian in an accident of similar severity. Considering the C-ratio and throw distances, both ATDs deliver similar results. Regarding the dummy "injuries", a unique feature of the Biofidelic Dummy, the described injuries correspond well to those of pedestrians.

Introduction

Severe vehicle-vehicle accidents usually cause distinctive damages as well as scratch marks on the road surface, which experts can exploit in order to reconstruct the accident. On the other hand, however, even lethal pedestrian-vehicle accidents often lead neither to significant traces on the road surface nor to a damage pattern which allows precise reconstruction of the vehicle's collision speed. This lack of evidence often complicates the work of experts reconstructing such kinds of accidents. Therefore, a need existed to improve the preciseness of accident reconstruction when pedestrians had been involved.

In order to achieve an improvement in accident reconstruction in this field, there seemed to be a need for a surrogate of an anthropomorphic testing device (ATD), which was able to deliver realistic vehicle damages as well as damages on itself, which allow finding a correspondence between dummy damages and injury probability. As such, a team of students under the guidance of one of the others had developed a biofidelic dummy. The aim was to design a dummy capable of causing realistic vehicle damages and furthermore to cause damages to itself comparable to typical injuries, which pedestrians sustain in a similar impact with a vehicle, in order to use the data gathered by conducting crash tests to reconstruct real pedestrian-vehicle accidents or to assess the benefit of changes to vehicle designs and hence helping to improve pedestrian safety [1].

The objective of this research was to analyse and verify the biofidelity of this human surrogate in pedestrian-vehicle crash tests. In this study, the reconstruction of a real high-speed crash

Methods and used equipment

DEKRA and AXA Winterthur Insurance have conducted nine crash tests with the Biofidelic Dummy in Wildhaus, Switzerland in the summer of 2018. The results have been compared with previously conducted crash tests with the Žilina Dummy, and results of post-mortem human subject (PMHS)-tests obtained from published research papers as well as 21 well-documented real-world pedestrian accidents. See table 1 for an overview of the crash tests.

crash test	vehicle	collision speed	braking	dummy
wh18.22	BMW 1 Series 2004	75 km/h	pre-crash	biofidelic
wh18.23	BMW 1 Series 2004	99 km/h	in-crash	biofidelic
wh18.24	VW Touareg 2003	75 km/h	pre-crash	biofidelic
wh18.25	VW Touareg 2003	99 km/h	in-crash	biofidelic
wh18.26	VW Passat Variant 2006	75 km/h	pre-crash	biofidelic
wh18.27	VW Passat Variant 2006	99 km/h	in-crash	biofidelic
wh18.28	Mercedes A-Class 2005	72 km/h	pre-crash	biofidelic
wh18.29	Mercedes A-Class 2005	96 km/h	in-crash	biofidelic
wh18.34	VW Touareg 2003	27 km/h	in-crash	biofidelic
wh08.27	Ford Galaxy 1998	40 km/h	pre-crash	Žilina
wh08.28	BMW 523i 1998	40 km/h	pre-crash	Žilina
wh08.29	Toyota Avensis 1998	40 km/h	pre-crash	Žilina
wh10.12	Fiat Punto 1996	55 km/h	late or unbraked	Žilina

***Table 1**. Overview of the crash tests.*

The crash test videos have been analysed by the programme "FalCon" (FalCon eXtra, Version 5.05.0003, 1998 – 2006 FalCon GmbH) to obtain the dummy trajectories and the C-ratio. The frame rate of the videos is 500 pictures/s. Time is set to zero at the point of first contact between the dummy and vehicle, which is visualised by means of a light signal mounted on top of the vehicle. The coordinate system, which is required for the programme to make its calculations, has its origin at the first target on the vehicle. The x-direction faces in the direction of travel, while the y-direction faces upwards. The dummy targets, used by the programme to track the dummy movements, had to be applied manually to the dummy within the programme. Targets were applied to the head, hip and foot. Each body region was analysed three-times and the average value was calculated, in order to reduce the errors stemming from manually placing the targets on the dummy. Every 10th picture has been analysed, i.e. the time interval be-tween the different measurements is 0.02 s. "FalCon" provides "txt"-files as data output, which have been uploaded into "Excel", with which the lines have been drawn. The final trajectory graphs have been created with "Corel-Draw".

"Autopsies" of the Biofidelic Dummy have been performed, in order to obtain the damages the dummy sustained during the crash tests and to translate those damages to comparable injuries of a human being.

Results and discussions

Dummy Trajectories

Biofidelic Dummy

Figure 1 displays the dummy trajectories of the crash tests wh18.22 and wh18.23.

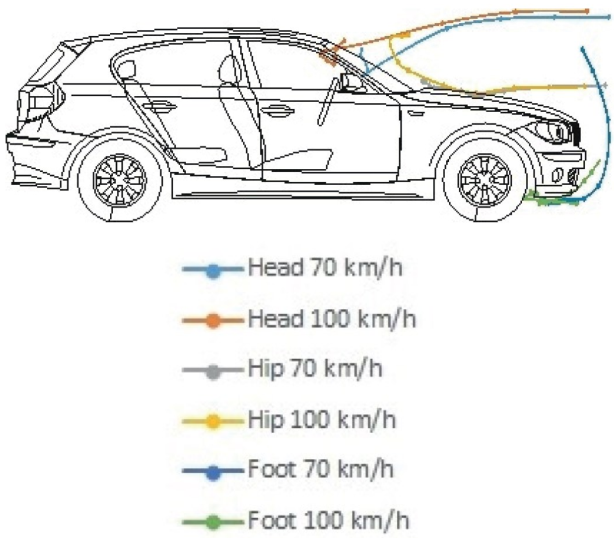

***Figure 1**. Dummy trajectories of crash tests wh18.22 and wh18.23.*

The "suck-below" effect, where the pedestrian's foot is sucked below the vehicle's front-end spoiler due to friction and inertia forces, be-comes more accentuated with an increase in collision speed. This effect can induce large bending and shear forces close to the talocalcanean joint. The magnitude of this "suck-below" effect further influences the kinematics of the lower extremities. While the legs are catapulted higher into the air at the lower collision speed, the lower extremities remain rather stuck to the vehicle's front due to the larger "suck-below" effect at the higher collision speed.

In the meantime, however, the ATD's torso is accelerated and moves along the vehicle's contour, leading to extensive stretching.

Without the wet suit, the Biofidelic Dummy would most likely have been torn apart. The probability of dis-memberment was analysed by [2]. They report a probability of dismemberment at a collision speed of 100 km/h of 0.281947 as mean, 0.157408 as lower and 0.514652 as upper value. The extensive stretching behaviour of the Biofidelic Dummy therefore does not seem to be unrealistic, but due to a lack of cadaveric tests at such high collision speeds it is difficult to assess the exact biofidelity of that behaviour.

In crash test wh18.22, the ATD's thigh is pushing backwards the left headlight assembly. This creates a sharp edge at the front part of the left fender. As the Biofidelic Dummy continues to slide onto the bonnet, this sharp edge pierces the ATD's leg. Such injuries are known from real-world accidents.

The head impacts the windscreen at 70 km/h, while the head impacts the roof leading edge at 100 km/h. Hence, the head moves further along the vehicle's contour with an increase in collision speed.

The hip is also further elevated at the higher collision speed, partially due to the extensive stretching behaviour of the Biofidelic Dummy.

Žilina Dummy

Figure 2 displays the dummy trajectories of crash test wh08.27.

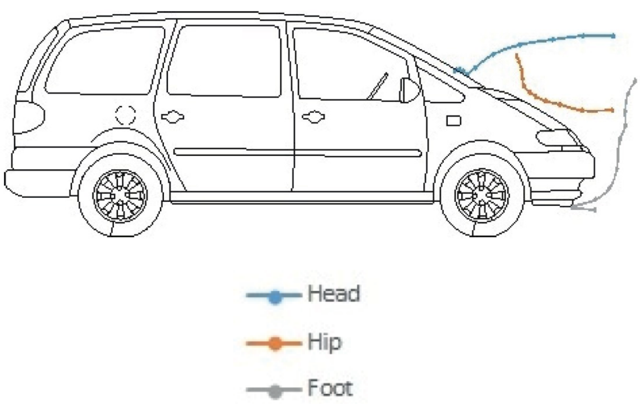

***Figure 2**. Dummy trajectories of crash test wh08.27.*

Here, the "suck-below" effect is much less pronounced. This has two reasons. Firstly, the collision speed of 40 km/h is much lower than the collision speeds of 70 km/h and 100 km/h used with the Biofidelic Dummy, meaning that the effect is less accentuated. Secondly, the Žilina Dummy is made of steel. Thus, the ATD's bones bend less than those of the Biofidelic Dummy and can further not huddle against the vehicle's contour in the same way as the latter's one.

The lower extremities are immediately catapulted away from the vehicle and the ATD rotates onto the bonnet around its centre of mass (*CoM*). The legs' collision with the bumper is elastic.

As the torso of the Žilina Dummy rolls onto the bonnet, the ATD props itself on its arm, before the head subsequently impacts the windscreen. The rotation around the CoM continues.

Comparison between Biofidelic Dummy and

Žilina Dummy

In contrast to the Biofidelic Dummy, which is a pseudoelastic body, the Žilina Dummy is an elastic body.

Considering crash test wh08.27, a speed for the leg of 44.87 km/h was recorded 0.02 s after impact. With a collision speed of 40 km/h, this equals to a coefficient of restitution of e = 1.12. Normally, however, $e \leq 1$, but the determination of the dummy's velocity via the programme "FalCon" is afflicted with errors. Thus, it can be concluded that the collision is perfectly elastic.

Human tissue, however, is pseudoelastic, which means that the tissue behaves plastically while a force is applied, and elastically when the force is removed. Hence, the Biofidelic Dummy's tissue, which has similar pseudoelastic characteristics as human tissue, is deformed by the impact force and causes the legs to huddle against the vehicle's front. Due to this plastic behaviour, impact energy is absorbed, which means that less energy is available for the legs to be catapulted away. In case of crash test wh18.22, for example, e = 0.63.

The Žilina Dummy remains stiff throughout the whole impact and there is no stretching behaviour as compared with the Biofidelic Dummy.

Comparison with PMHS-Tests

In order to validate the biofidelity of the trajectories of both the Biofidelic and Žilina Dummy, the findings were compared with PMHS-tests published in research papers.

[3] conducted four PMHS-tests. They used a mid-sized sedan and a small city car, and the collision speed was 40 km/h. The four cadavers were male and exhibited no pre-existing fractures, lesions or other bone pathology, though three of the subjects had poor bone mineral density. [4] conducted three PMHS-tests at 40 km/h with a small sedan.

The PMHS's trajectories were compared with those of the Biofidelic Dummy being hit by the VW Passat and the Žilina Dummy being hit by the Toyota Avensis. The VW Passat and the Toyota Avensis were chosen for comparison as they should equal the mid-sized sedan in weight the most and should also have a similar front-end geometry. However, the different collision speeds must be taken into account, making a direct comparison somewhat complicated.

As outlined in [5] by one of the authors, the trajectories of the Biofidelic Dummy are much more human-like than those of the Žilina Dummy. In particular, the "propping" effect of the latter is unnatural. These findings come, however, with the caveat that the collision speeds are quite different. Nonetheless, the tendency that the Biofidelic Dummy behaves more human-like cannot be dismissed.

Vehicle Damages

For reconstruction purposes, it is very important that the vehicle damages caused by the ATD are comparable to those caused by the pedestrian. Of the nine crash tests with the Biofidelic Dummy conducted by DEKRA in the summer of 2018, crash tests wh18.22 and wh18.26 are the only ones comparable to two of the analysed real-world accidents. The collision speed, dum-my/pedestrian height and weight are still within an acceptable deviation.

Considering the Žilina Dummy, all four crash tests are considered, even though the collision speed is much lower.

Next to the slightly different collision speeds and differences in dummy and pedestrian anthropometry, differences in front-end geometry and local vehicle stiffness should also be kept in mind.

Biofidelic Dummy vs. Pedestrian

The damages to the bonnet leading edge caused by both the Biofidelic Dummy and the two pedestrians are shown in figure 3.

In both real accidents, the damages to the bonnet leading edge were caused by the thigh

Figure 3. *Vehicle damages Biofidelic Dummy vs. pedestrian. (Top left: wh18.22; Bottom left: wh18.26; Top right: accident 1; Bottom right: accident 2).*

and hip rolling over the edge and onto the bonnet. The bonnet is slightly indented and the headlight assembly of the BMW is pushed backwards.

Considering the two crash tests, the damages were also caused by the thigh and hip as the dummy rolled onto the vehicle. Again, the bonnet is slightly indented. The headlight assembly of the BMW is also pushed backwards and the glass is fractured.

The damages produced by the Biofidelic Dummy are comparable to those seen in the real accidents.

Žilina Dummy vs. Pedestrian

The damages to the bonnet leading edge caused by both the Žilina Dummy and the two pedestrians are shown in figure 4.

Even though the collision speed is much lower in the crash tests, the damages are much more intense. The thigh and hip of the Žilina Dummy indented the bonnet leading edge much further than the two pedestrians did. Moreover, the bonnet is bulged by this impact, before the chest of the dummy indents it much deeper than the pedestrians did. The pattern of the damages is completely different and cannot be compared with the two real-world accidents.

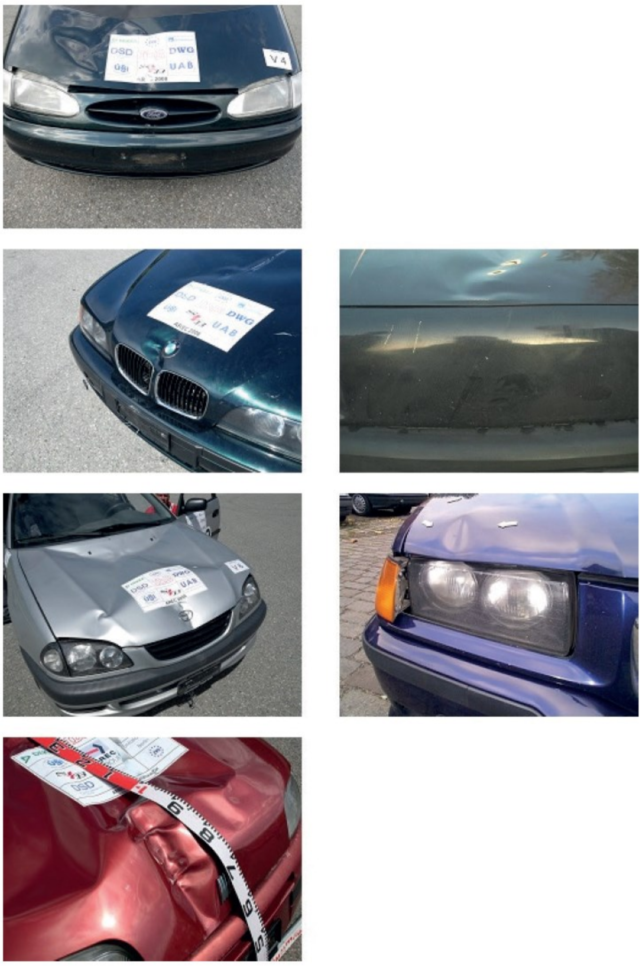

***Figure 4**. Vehicle damages Žilina Dummy vs. pedestrian. (Top left: wh08.27; Upper left: wh08.28; Lower left: wh08.29; Bottom left: wh10.12; Top right: accident 1; Bottom right: accident 2).*

As the Žilina Dummy is a rigid body, it can also cause scratch marks on the bonnet or even lacerate metal parts of the vehicle. Such damages cannot be caused by a human being.

The Žilina Dummy causes damages that are much more intense even at a lower collision speed. Hence, it can be concluded that the Žilina Dummy does not produce realistic damages and would suggest a lower collision speed when compared with a similar real-world accident.

C-Ratio

Static C-Ratio

The C-ratio is defined as the closing speed over collision speed, and is an important parameter in accident reconstruction. Collision speed is the speed with which the striking vehicle hits the pedestrian, and is there-fore a property of the vehicle. Closing speed is the speed with which the pedestrian’s body part to be analysed impacts with the striking vehicle, and is therefore a property of the pedestrian.

In practice, the C-ratio is determined using the pedestrian’s anthropometric data and the vehicle’s geometry. This geometrical C-ratio is determined using an internal DEKRA algorithm.

It shall be analysed in how far the ATD’s C-ratio determined using the geometrical approach matches the one determined by using crash test video analysis. As no specific body part shall be analysed in this instance, but rather the whole body, DEKRA uses the following convention in determining the closing speed of the whole body: The closing speed is determined by evaluating the *CoM’s* speed at just that moment when the whole dummy detaches from the vehicle.

The C-ratio is then computed by dividing the closing speed with the collision speed. By DEKRA convention, the C-ratio is not stated as $C = 0.9$ for example, but the result is multiplied by 100 to yield a C-ratio of $C = 90$.

Table 2 lists the determined C-ratios of the thirteen crash tests.

crashtest	C	C_g	C_{g5}	C_{g10}	C_{g15}	ΔC	ΔC_5	ΔC_{10}	ΔC_{15}	ΔC%	$\Delta C\%_5$	$\Delta C\%_{10}$	$\Delta C\%_{15}$
wh18.22	90	74	78	82	86	-16	-12	-8	-4	-17.78	-13.33	-8.89	-4.44
wh18.23	100	72	76	80	84	-28	-24	-20	-16	-28.00	-24.00	-20.00	-16.00
wh18.24	95	87	91	95	99	-8	-4	0	4	-8.42	-4.21	0.00	4.21
wh18.25	80	86	90	94	98	6	10	14	18	7.50	12.50	17.50	22.50
wh18.26	97	73	77	81	85	-24	-20	-16	-12	-24.74	-20.62	-16.49	-12.37
wh18.27	100	73	77	81	85	-27	-23	-19	-15	-27.00	-23.00	-19.00	-15.00
wh18.28	77	72	76	80	84	-5	-1	3	7	-6.49	-1.30	3.90	9.09
wh18.29	93	71	75	79	83	-22	-18	-14	-10	-23.65	-19.30	-15.05	-10.75
wh18.34	87	87	91	95	99	0	4	8	12	0.00	4.60	9.19	13.79
average										***15.95***	***13.66***	***12.22***	***12.02***
wh10.12	90	72	76	80	84	-18	-14	-10	-6	-20.00	-15.56	-11.11	-6.67
wh08.27	102	79	83	87	91	-23	-19	-15	-11	-22.55	-18.63	-14.71	-10.78
wh08.28	70	68	72	76	80	-2	2	6	10	-2.86	2.86	8.57	14.29
wh08.29	66	72	76	80	84	6	10	14	18	9.09	15.15	21.21	27.27
average										***13.63***	***13.05***	***13.90***	***14.75***

***Table 2**. C-ratios (the smallest deviation is marked in red).*

C is the C-ratio determined via video analysis and is the reference value. It is also called the analytical C-ratio. Depending on the impact characteristics, a correction factor of between 5% and 15% is applied to the geometrical C-ratio C_g. This is marked as C_g5, for example. The difference between the two C-ratio values is marked with *ΔC*, and the percentage-wise difference with *ΔC%*. A "minus" indicates that the value is less than the reference value.

While the average deviation decreases with an increase in the correction factor for the Biofidelic Dummy, the deviations are more or less the same for the Žilina Dummy, though the correction factor of 5% exhibits the smallest deviation. The respective deviation with no correction factor and a 5% correction factor for the Biofidelic Dummy is higher compared to the Žilina Dum-my, while with a correction factor of 10% and 15%, respectively, the average deviation is lower for the Biofidelic Dummy compared to the Žilina Dummy.

Regarding the Biofidelic Dummy, positive deviations only occur in crash tests conducted with the VW Touareg and the Mercedes A-Class. Looking at the Žilina Dummy, positive deviations occur in the crash tests with the BMW 5 Series and Toyota Avensis.

Considering the Biofidelic Dummy, *ΔC%* ~ 25 for all the cases where the dummy hit the roof leading edge and remained attached to it for at least a short time. In crash test wh18.28, the dummy impacted the roof leading edge, but detached immediately. As the different correction values are applied, the values for *ΔC%* all de-crease in a similar pattern. How different front-end geometries and the fact that the roof leading edge has been impacted affect this behaviour merits further investigation.

Throw Distance

Given that both the final position of the pedestrian as well as the point of collision are known, the throw distance can be used to determine the collision speed.

Throw distance charts have been developed by DEKRA based on crash tests with the Žilina Dummy and results from well-documented real-world pedestrian accidents. Different throw charts have been developed for complete, partial and streaking hits. Considering complete hits, one has to further distinguish between pre-crash and in-crash braking.

Regarding the four pre-crash braking crash tests with the Biofidelic Dummy, two of the throw distances lie within the boundaries, while one lies just above the upper boundary and the fourth throw distance lies outside of the empirically developed corridor. However, DEKRA accident analysts deemed the deviation still being within an acceptable range. The three pre-crash braking crash tests with the Žilina Dummy are also marked in the chart. Two of the three distances lie just below the lower boundary, while one lies outside the corridor. As the deviation is unacceptably high, data from the accident data recorder have been analysed. The data highlight the fact that the brakes were not applied with full force, and hence the ATD was not catapulted away from the vehicle, but "travelled" with the vehicle for a prolonged time. This falsified the throw distance, which is why the Ford Galaxy must be excluded. Figure 8 in the appendix shows the throw distance chart for complete hits and pre-crash braking.

Considering in-crash braking, only three of the four crash tests conducted with the Biofidelic Dummy can be analysed. In crash test wh18.27, the ATD penetrated the windscreen and got stuck. While the throw distance for the Mer-cedes A-Class lies within the boundaries, the throw distance for the BMW 1 Series lies outside the boundaries, but still within an acceptable range according to DEKRA accident analysts. Regarding the VW Touareg, however, the deviation is by far too big. But, by further ana-lysing the dynamics and kinematics of the ATD in this crash test, one realises that the ATD be-gins to slide off the fender quite immediately after impact and the complete hit hence becomes a partial hit. The throw distance lies well within the boundaries for partial hits. Thus, crash test wh18.25 is a special case, as the impact con-stellation equals to a complete hit, but turns into a partial hit due to the ATD kinematics and dynamics. This is explained by the flexibility of the Biofidelic Dummy. Like a human, the Biofidelic Dummy allows for torsional movement of the upper body relative to the pelvis. Thanks to this torsional movement of the upper body, the pelvis was turned sideways and thus slid off the fender. On the other hand, the Žilina Dummy does not allow for such movements as a rigid body. Figure 9 in the appendix displays the throw distance chart for complete hits and in-crash braking, and figure 10 in the appendix depicts the throw distance chart for partial hits.

It can be concluded that both the Biofidelic and Žilina Dummy “produce” expected throw distances. However, as the throw distance charts have been developed partially based on crash tests with the Žilina Dummy, the charts are slightly biased towards the Žilina Dummy. Nonetheless, the results from the Biofidelic Dummy are very pleasing and further corroborate the validity of the throw distance charts.

“Dummy Injuries”

“Autopsies” of the eight Biofidelic Dummies have been conducted at the “Bureau for Accident Reconstruction Berlin”.

In [6], one of the authors analysed the correlations between collision parameters, vehicle damages and pedestrian injuries and concluded that the fracture patterns of long bone fractures in the lower limbs, knee joint injuries, injuries to the ankle, pelvic injuries and head injuries can be used for reconstruction purposes. Here, only the fracture patterns of the lower leg’s long bones and knee joint injuries are presented in more detail, as those “injuries” are mimicked most precisely by the Biofidelic Dummy.

<u>Fracture Patterns of the Lower Leg’s Long Bones</u>

The characteristic wedge-shaped fracture pattern, known as the Messerer’s wedge fracture, can be often found in pedestrians hit by a vehicle [7]. The apex points in the direction of the vehicle’s velocity vector and is thus indicative of the direction of impact.

While the fracture of the Biofidelic Dummy’s lower leg does not exhibit the characteristic two faces of the Messerer’s wedge fracture with the apex showing in the impact direction, a unique fracture pattern can be still observed. Initially, the fracture surface is flat and then ends with a protrusion on one of the two fracture surfaces. As with the apex of the Messerer’s wedge fracture, this protrusion always indicates the impact direction.

Bone is a heterogeneous material, whereas the ATD’s bones are made of a homogeneous material with similar strength. This difference explains the different fracture patterns observed in human beings and the Biofidelic Dummy. Not-withstanding, the Biofidelic Dummy exhibits a fracture pattern comparable to the Messerer’s wedge fracture which can be used as a supporting factor in determining the impact direction. Figure 5 shows the fracture pattern observed in the Biofidelic Dummy used in crash test wh18.23.

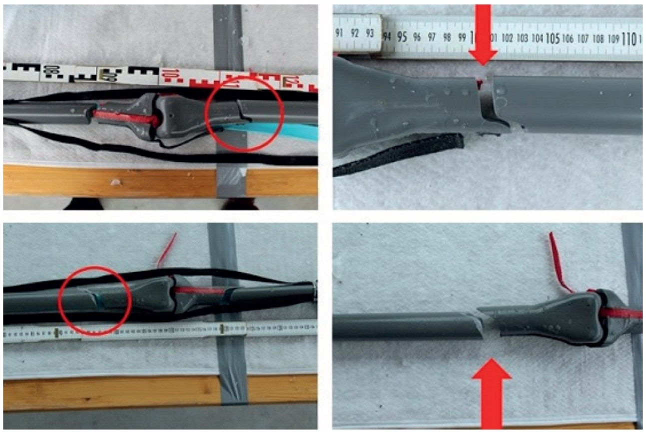

Figure 5. *Messerer's wedge fracture in the Biofidelic Dummy used for crash test wh18.23 (Top: Left side; Bottom: Right side; Red circle: Location of wedge-shaped fracture; Red arrow: Impact direction).*

<u>Knee Joint Injuries</u>

The knee injuries sustained by the pedestrian can be classified ac-cording to their mechanism, namely avulsive or compressive. The resulting injuries to the condyles, the collateral ligaments and the cruciate ligaments are indicative of the impact direction. While valgus flexion was primarily found in lateral hits, varus flexion was found in medial ones.

The Biofidelic Dummy's knees have a very humanoid anatomy. The biofidelity of the dummy's knee joint injuries is analysed by means of the left knee joints of the ATDs used in crash tests wh18.23 and wh18.25, which are shown in figures 6 and 7. The underlying injury mechanism is varus flexion.

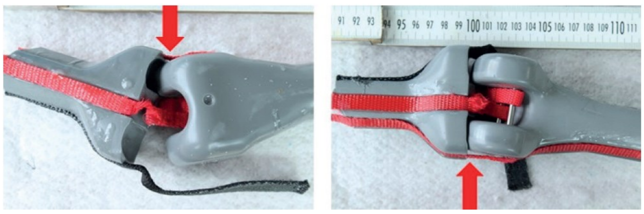

Figure 6. *Knee injury of the Biofidelic Dummy used in crash test wh18.23 (Left: Front view; Right: Rear view; Red arrow: Impact direction).*

Considering crash test wh18.23 and figure 6, the black tape, representing the lateral collateral ligament, has been torn off the femur. The tapes are glued to the bones. Here, the attachment site was weaker than the tape itself, which is why the tape was torn off and did not rupture. In reality, however, the ligament would rupture. Nonetheless, this damage to the Biofidelic Dummy's knee can be interpreted as a ruptured lateral collateral ligament. Moreover, both the anterior and the posterior cruciate ligaments are frayed. These "injuries" coincide with those found by [8] in human beings.

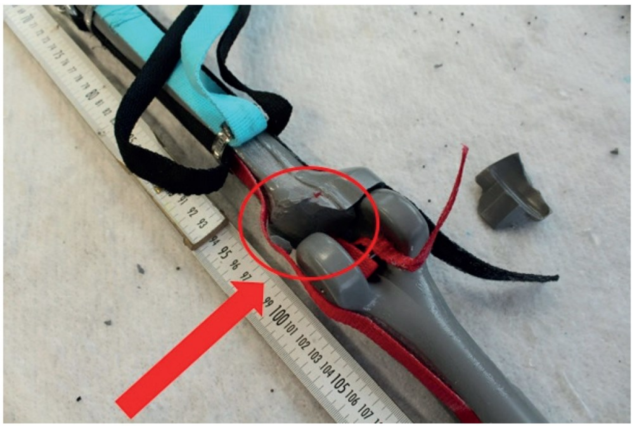

Figure 7. *ear view of the knee injury of the Biofidelic Dummy used in crash test wh18.25 (Red circle: Location of medial tibial condyle fracture; Red arrow: Impact direction).*

Considering crash test wh18.25 and figure 7, them induced bending was even stronger, resulting in the fracture of the medial tibial condyle. In addition, the lateral collateral ligament as well as both the anterior and posterior cruciate ligaments were ruptured. The medial collateral lig-ament was also frayed by the impact.

Evaluation Matrix

In [5], one of the authors evaluated the performance of the Biofidelic Dummy and Žilina Dummy.

The performance criteria are entirely based on the demands of DEKRA and are hence subjective. Another organisation may have different demands and would thus come to different conclusions. The evaluation is further solely based on the results from the crash tests performed by DEKRA and AXA Winterthur Insurance. Hence, one must bear in mind that the evaluation is based on a rather small sample size.

Biofidelic Dummy

The evaluation matrix of the Biofidelic Dummy is shown in table 3.

biofidelic dummy	++	+	0	-	--
biofidelity	X				
realistic throw distances		X			
realistic vehicle damages	X				
usability in a collision speed interval of 40 km/h to 100 km/h	X				
cost			X		
durability					X

***Table 3**. Evaluation matrix of the Biofidelic Dummy.*

Considering "biofidelity", "realistic vehicle dam -ages" and "usability in a collision speed interval of 40 km/h to 100 km/h", the Biofidelic Dummy scores highly.

It scores poorly considering "durability".

The ATD's performance concerning "realistic throw distances" is good.

The criterion "cost" is deemed as being acceptable.

Žilina Dummy

The evaluation matrix of the Žilina Dummy is shown in table 4.

Žilina dummy	++	+	0	-	--
biofidelity					X
realistic throw distances		X			
realistic vehicle damages					X
usability in a collision speed interval of 40 km/h to 100 km/h	X				
cost	X				
durability	X				

***Table 4**. Evaluation matrix of the Žilina Dummy.*

Considering "usability in a collision speed interval of 40 km/h to 100 km/h", "cost" and "durability", the Žilina Dummy scores highly.

It scores poorly considering "biofidelity" and "realistic vehicle damages".

The ATD's performance concerning "realistic throw distances" is good.

Limitations

While the representational crash tests conducted by DEKRA and AXA Winterthur Insurance with the Biofidelic Dummy were performed at roughly 70 km/h and 100 km/h, the Žilina Dummy and PMHS-tests had been conducted at roughly 40 km/h. This makes a direct comparison somewhat complicated due to different impact energies. But former crash tests had been conducted successfully with the Žilina Dummy as well as the Biofidelic Dummy at impact speeds between roughly 40 km/h and 75 km/h. Nonetheless, different vehicles were used, which also has an impact on dummy/PMHS dynamics and kinematics.

As the dummy targets were placed manually on the ATDs in the video analysis programme "FalCon" (FalCon eXtra, Version 5.05.0003, 1998 – 2006 FalCon GmbH), the determination of the trajectories and C-ratios is further afflicted with minor inaccuracies. However, each value was computed three times and the average has been taken, in order to minimize the inaccuracies as much as possible.

The Biofidelic Dummy can further only mimic fractures and not injuries to other tissues and organs.

Conclusions

The Biofidelic Dummy already exhibits a high degree of biofidelity. Its trajectories are comparable with those of PMHSs and this ATD also creates realistic vehicle damages. This allows to more correctly determine the collision speed. The obtained C-ratios are also good and the deviations to those obtained by the Žilina Dummy are minimal. It can be concluded that the current procedure of determining the geometrical C-ratio based on the Žilina Dummy is still valid and can be further used. The method should only be revised, in order to further refine the correctness of the results. This, however, merits further investigations. The throw distances obtained with the Biofidelic Dummy are good. The unique feature of the Biofidelic Dummy is its ability to mimic injuries a pedestrian would suffer in a pedestrian-vehicle accident of similar severity. The "injuries" of the ATD resemble those of a pedestrian pretty well, especially those of the knee joint. Thus, the Biofidelic Dummy enables expert witnesses to reconstruct a pedestrian/vehicle accident and to obtain realistic vehicle damages, throw distances and injuries. This opens up new possibilities in the field of accident reconstruction.

However, this biomechanical validation is solely valid when the Biofidelic Dummy is used as a surrogate in pedestrian-vehicle crash tests. Shall the Biofidelic Dummy be used as a car occupant or cyclist, for example, further validations will become necessary.

Disclosures

No financial conflicts of interest are reported.

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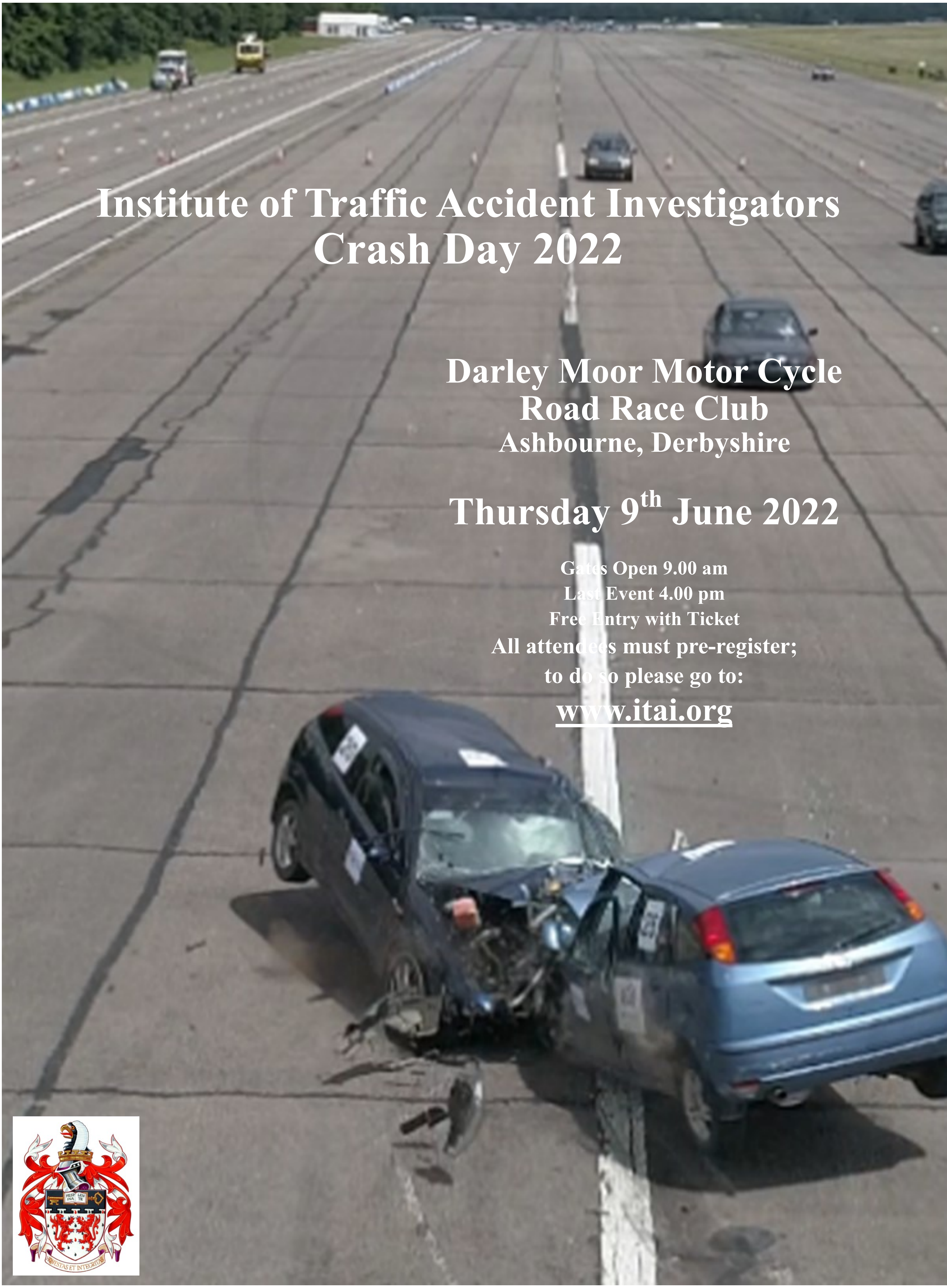
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Darley Moor Motor Cycle
Road Race Club
Ashbourne, Derbyshire
Thursday 9th June 2022
Gates Open 9.00 am
Last Event 4.00 pm
Free Entry with Ticket
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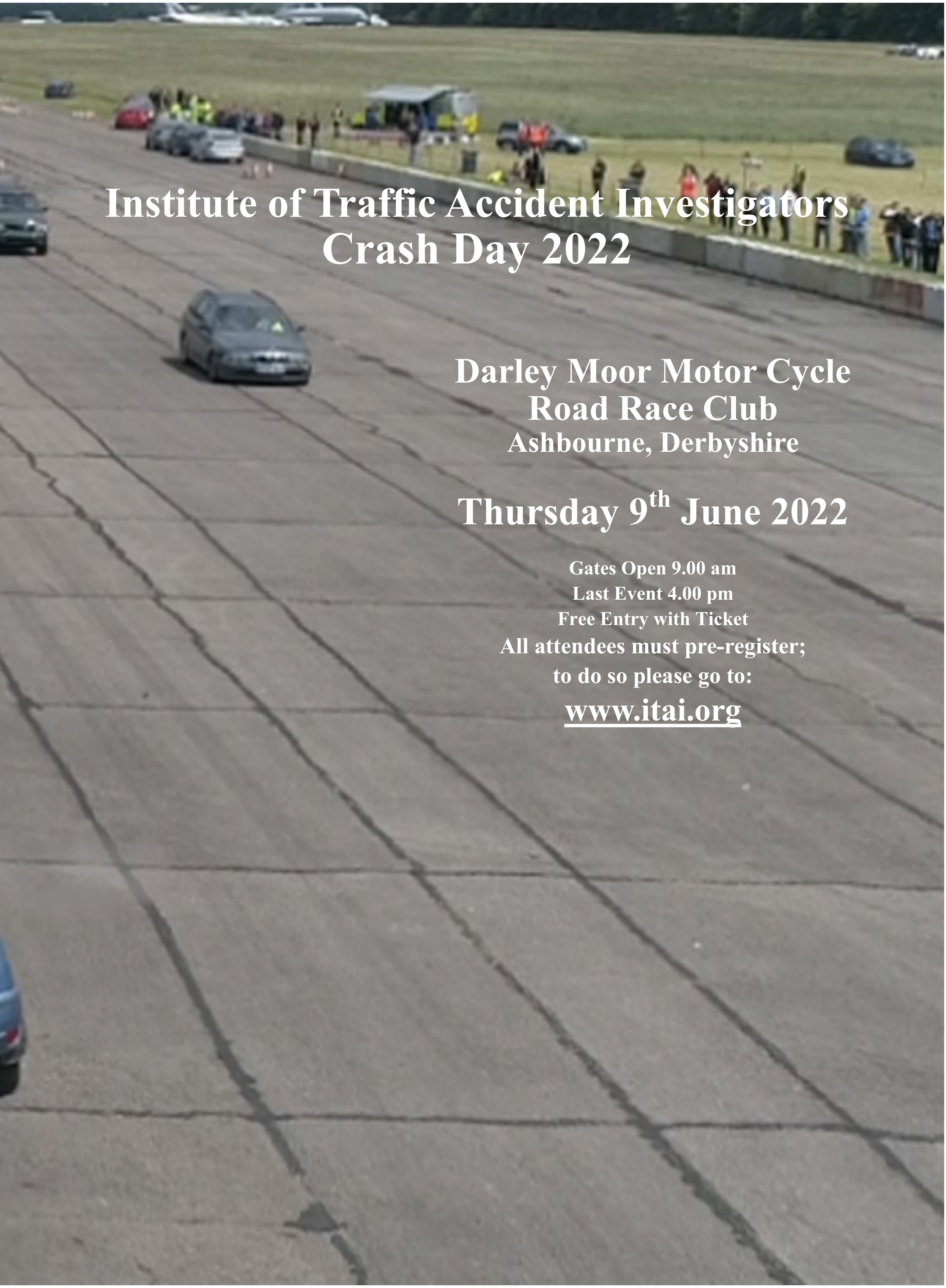
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Impact

Submissions invited

Next Edition July/August 2022

As ever, the Editor would be very pleased to hear from members, non-members or subscribers, who have produced material that they feel would be of interest to readers of *'Impact'*. Details of research projects or relevant collision investigation testing would be particularly welcome. Attracting sufficient numbers of articles for publication in the Institute's journal remains a difficulty! Whilst the Editor is delighted to receive papers from overseas contributors, a greater supply of 'home grown' material would also be very welcome.

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